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Nancy Ma

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
North Carolina State University
Campus Box 7910, 2601 Stinson Drive
Raleigh, NC 27695-7910

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Dr. Arje Nachman
Air Force Office of Scientific Research
875 North Randolph St., Rm 3112
Arlington, VA 22203

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14. ABSTRACT
Single crystals of doped and alloyed antimonide-based semiconductors are needed for Air Force Applications because they serve as transparent, lattice-matched epitaxial growth templates for detectors. High-performance devices rely on good compositional homogeneity in the bulk substrate which is cut from wafers sliced from the crystal. Several important processes are being developed at AFRL in Hanscom AFB, which are the vertical gradient freezing process using submerged heater growth, the vertical Bridgman process using submerged heater growth, and the magnetic liquid-encapsulated Czochralski process. Because molten semiconductors are excellent electrical conductors, these processes apply magnetic and electric fields to control the melt motion and thus the convective transport of species during growth in order to optimize the properties of the crystal. Asymptotic and numerical modelling of these processes have provided predictions of the transport in the melt and of the compositional distribution in the crystal.

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Technical Summary

Three important processes which are used to grow single crystals of semiconductors are being developed at AFRL in Hanscom AFB which are the vertical gradient freezing process using submerged heater growth, the vertical Bridgman process using submerged heater growth, and the magnetic liquid-encapsulated Czochralski process. These processes as well as the Bridgman-Stockbarger process have been investigated. During the growth of any semiconductor, a major objective is to minimize segregation of dopant or alloy components in the crystal. Because molten semiconductors are excellent electrical conductors, magnetic fields or electric fields or a combination of both can be used to control the melt motion and thus the convective species transport during growth in order to promote compositional homogeneity. Asymptotic and numerical models using Chebyshev spectral collocation methods are developed. Key results are summarized here.

The traditional Bridgman-Stockbarger process in steady magnetic fields produces crystals with severe segregation. Therefore other means are needed to optimize the crystal growth process in order to produce crystals with minimal segregation. The vertical gradient freezing process using a submerged heater in a combination of steady magnetic and electric fields produced crystals with axial uniformity and with little radial segregation. The vertical Bridgman process in rotating magnetic fields also produced crystal with axial uniformity and with little radial segregation, but a crystal growth in combination of magnetic and electric fields with the equivalent parameters produced a crystal with less segregation. Investigations of magnetic liquid-encapsulated Czochralski crystal growth in rotating magnetic fields are in progress and preliminary results indicate that this is a promising means to minimize radial segregation.

People Involved

Dr. P. Becla, Solid State Scientific, Hollis, NH
Dr. D. F. Bliss, Sensors Directorate, U.S. Air Force Research Laboratory, Hanscom AFB, MA
Dr. G. G. Bryant, Sensors Directorate, U.S. Air Force Research Laboratory, Hanscom AFB, MA
Dr. G. W. Iseler, Iseler Associates, Chelmsford, MA

Journal Articles

1. Xianghong Wang, Nancy Ma, David F. Bliss, Gerald W. Iseler and Piotr Becla, "Combining static and rotating magnetic fields during modified vertical Bridgman crystal growth," AIAA *Journal of Thermophysics and Heat Transfer*, submitted.
2. Mei Yang, Nancy Ma, David F. Bliss and George G. Bryant, "Melt motion during liquid-encapsulated Czochralski crystal growth in steady and transverse rotating magnetic fields," *International Journal of Heat and Fluid Flow*, accepted.
3. Xianghong Wang and Nancy Ma, "Semiconductor crystal growth by the vertical Bridgman process with rotating magnetic fields," ASME *Journal of Heat Transfer*, accepted.
4. Xianghong Wang, Nancy Ma, David F. Bliss and Gerald W. Iseler, "Solute segregation during modified vertical gradient freezing of alloyed compound semiconductor crystals with magnetic and electric fields," *International Journal of Heat and Mass Transfer*, vol. 49, no. 19/20, pp. 3429-3438, September 2006.
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15. Stephen J. LaPointe, Nancy Ma and Donald W. Mueller, Jr., "Growth of binary alloyed semiconductor crystals by the vertical Bridgman-Stockbarger process with a strong magnetic field," ASME *Journal of Fluids Engineering*, vol. 127, no. 3, pp. 523-528, May 2005.
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19. Martin V. Farrell and Nancy Ma, "Macrosegregation during alloyed semiconductor crystal growth in strong axial and transverse magnetic fields," *International Journal of Heat and Mass Transfer*, vol. 47, no. 14/16, pp. 3047-3055, July 2004.

CONFERENCE ARTICLE

1. Xianghong Wang, Nancy Ma, David F. Bliss and Gerald W. Iseler, "Semiconductor crystal growth by modified vertical gradient freezing with electromagnetic stirring," AIAA 43rd Aerospace Sciences Meeting and Exhibit, AIAA Paper #2005-0916, Reno, NV, January 2005.

STUDENT THESES & DISSERTATIONS

1. Mei Yang, "Liquid-encapsulated Czochralski growth of compound semiconductor crystals with steady and rotating magnetic fields," Ph.D. awarded December 2006.
2. Xianghong Wang, "Semiconductor crystal growth by the vertical Bridgman and gradient freezing processes with applied fields," Ph.D. awarded August 2006.
3. Stephen J. LaPointe, "Growth of binary alloyed semiconductor crystals by the vertical Bridgman-Stockbarger process with a strong magnetic field," M.S. awarded December 2004.